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Energy for sustainable development: A case of developing countries

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ABSTRACT

Today, there are 1.4 billion people around the world that lack access to electricity, some 85% of them in rural areas. Without additional dedicated policies, by 2030 the number of people drops, but only to 1.2 billion. Some 15% of the world's population still lack access, the majority of them living in Sub-Saharan Africa. The number of people relying on the traditional use of biomass is projected to rise from 2.7 billion today to 2.8 billion in 2030. Addressing these inequities depends upon international recognition that the projected situation is intolerable, a commitment to effect the necessary change, and setting targets and indicators to monitor progress. A new financial, institutional and technological framework is required, as is capacity building in order to dramatically scale up access to modern energy services at the local and regional levels. In this paper, we discussed the energy situation of the developing countries for sustainable development.

Contents

1. Introduction

Making energy supply secure and curbing energy's contribution to climate change are often referred as the two over-riding challenges faced by the energy sector on the road to a sustainable future [1]. It is the alarming fact that today billions of people lack access to the most basic energy services, electricity and clean cooking facilities, and, worse, this situation is set to change very little over the next 20 years, actually deteriorating in some respects. This is shameful and unacceptable [2–4].

Lack of access to modern energy services is a serious hindrance to economic and social development and must be overcome if the UN Millennium Development Goals (MDGs) are to be achieved [5–10]. The number of people who need to gain access to modern

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Table 1
Number of people without access to electricity and relying on the traditional use of biomass, 2009 (million).

	Number of people lacking access to electricity	Number of people relying on the traditional use of biomass for cooking
Africa	587	657
Sub-Saharan Africa	585	653
Developing Asia	799	1937
China	8	423
India	404	855
Other Asia	387	659
Latin America	31	85
Developing countries[a]	1438	2679
World[b]	1441	2679

[a] Includes Middle East countries.
[b] Includes OECD and transition economies.

Table 2
Number of people without access to electricity by region (million).

	2009			2020
	Rural	Urban	Total	Total
Africa	466	121	587	644
Sub-Saharan Africa	465	120	585	640
Developing Asia	716	82	799	650
China	8	0	8	2
India	380	23	404	342
Other Asia	328	59	387	307
Latin America	27	4	31	16
Developing countries[a]	1229	210	1438	1350
World[b]	1232	210	1441	1352

[a] Includes Middle East countries.
[b] Includes OECD and transition economies.

energy services and the scale of the investments required must be estimated, both in the period to 2015 and over the longer term, in order to achieve the proposed goal of universal access to modern energy services by 2030 [11].

The numbers related to household access to energy are striking. It is estimated that 1.4 billion people lack access to electricity and that 2.7 billion people rely on the traditional use of biomass for cooking (Table 1) [6]. The projections suggest that the problem will persist and 1.2 billion people still lack access to electricity in 2030, 87% of them living in rural areas (see Table 2) [3]. Most of these people will be living in Sub-Saharan Africa, India and other developing Asian countries (excluding China). In the same scenario, the number of people relying on the traditional use of biomass for cooking rises to 2.8 billion in 2030, 82% of them in rural areas [1–7].

The greatest challenge is in Sub-Saharan Africa, where today only 31% of the population has access to electricity, the lowest level in the world. If South Africa is excluded, the share declines further, to 28%. Residential electricity consumption in Sub-Saharan Africa, excluding South Africa, is roughly equivalent to consumption in New York. In other words, the 19.5 million inhabitants of New York consume in a year roughly the same quantity of electricity, 40 TWh, as the 791 million people of Sub-Saharan Africa [6].

2. A broad look at energy issues

Current demographic, economic, social, and technological trends pose major challenges to the long-term sustainability of the global energy system [2–5]. If governments do not implement policies beyond those already planned between now and 2030, it is projected that [6]:

- energy consumption will increase by over half (53%);
- the energy mix will remain fairly stable and dominated by fossil fuels (80% share);
- energy-related CO_2 emissions will increase by over half (55%); and
- large populations of the world's poor will continue to lack access to electricity (about 1.5 billion) and modern cooking and heating services (about 2.5 billion).

Table 3
World energy demand by source (Mtoe).

Energy source	1980	2000	2008	2020
Coal	1792	2292	3286	4124
Oil	3107	3655	4320	4654
Gas	1234	2085	2586	3046
Nuclear	186	676	723	920
Hydropower	148	225	276	389
Biomass and waste	749	1031	1194	1436
Other renewables	12	55	82	196
Total world	7228	10,018	12,467	14,765

Mtoe, million tons of oil equivalent.

In this scenario, energy consumption increases from 12,467 million tons of oil equivalent (Mtoe) in 2008 to 14,765 Mtoe in 2020 (Table 3) [3]. Over 70% of this growth is expected to come from developing countries, which overtake OECD countries as energy consumers sometime around 2014. Nearly half of the increase in global primary energy use goes to generating electricity and one-fifth of the increase to meeting transport needs [3–6].

Growth in energy use and emissions is expected to be particularly marked in some sectors. The sectoral contributors to growth in energy consumption are expected to be power generation (35%), industry (15%), transport (12%) and buildings (6%) in developing countries, followed by power generation (11%) and transport (6%) in OECD countries [2]. Improving efficiency and reducing carbon dioxide (CO_2) emissions should receive early attention in these high growth areas, because these goals are easier and cheaper to attain at the time of new construction than at later retrofit stages [12,13].

It is predicted that the global energy mix will remain fairly stable and dominated by fossil fuels to 2030 due to the size and inertia of the energy system and the inability to change it quickly. In this case, no fuel's share of the mix changes by more than a few percentage points as shown in Fig. 1. Fossil fuels remain the largest energy source accounting for about 80% of global demand in 2008 and 78% in 2030 [6]. The consumption of each fossil fuel grows at different rates, so their shares of the total shift slightly – oil falls from 34% of the total in 2008 to 32% in 2030; coal rises from 25% to 26%; and gas rises from 21% to 23%. Concerns about continued high consumption of oil and gas

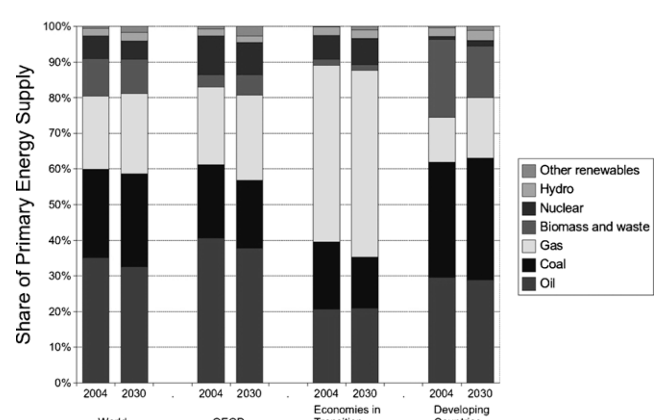

Fig. 1. Fuel profile of primary energy use.

raise questions of supply security. China and India account for almost four-fifths of the incremental demand for coal. Renewable energy and nuclear power shift to a similarly small degree [10]. Hydropower's share of primary energy use rises slightly [6]. The share of biomass decreases as developing countries switch to modern commercial energy, offsetting the growing use of biomass as feedstock for biofuel production and for power generation. Non-hydro renewables such as wind, solar and geothermal grow the quickest, but from a small base [5,6,14].

While greenhouse gas (GHG) emissions and the ensuing climate change are not the only environmental problems confronting the energy sector, they are the most universal and most pressing. In the reference scenario, energy-related CO_2 emissions increase from 27.1 Gt CO_2/year in 2008 to 40.4 Gt CO_2/year in 2030. Over three-quarters of this growth come from developing countries. China, which overtakes the USA as the world's biggest emitter before 2010, accounts for 39% of the global increase between 2004 and 2030. Its emissions more than double between 2004 and 2030, driven by strong economic growth and heavy reliance on coal in power generation and industry. India accounts for 10% of the increase in global emissions [6–8,13].

The sectoral contributors to CO_2 emission growth are forecast as coal-based power generation (32%), oil use in transport (13%), coal use in nonpower sectors (9%), gas-based power generation (8%) and oil used in nonpower sectors (7%) in developing countries. These projections concerning energy and environmental trends are not inevitable; there are many policies that if implemented could change them. According to the alternative scenario based on enlightened policies, it is possible to substantially alter the course of energy development in the next half century and to make the energy system more sustainable. To achieve this, countries need to adopt all of the policies related to energy security and energy-related CO_2 emissions that they are currently considering [6,13].

These policies include efforts to improve efficiency in energy production and use, increase reliance on non-fossil fuels, and sustain the domestic supply of oil and gas within net energy-importing countries. They would yield substantial savings in energy consumption and reductions in CO_2 emissions. Moreover, these benefits would be achieved at a lower total investment than if such action is postponed. While suppliers' investments decrease, consumers' investments increase but this is more than offset by lifecycle energy cost savings. The cost of fuel saved by consumers is estimated at USD 8.1 trillion, more than offsetting the extra demand-side investments required to generate these savings [13,15].

Policies encouraging more efficient production and use of energy could contribute almost 80% of the avoided CO_2 emissions in 2030, with the remainder gained from fuel substitution. More efficient use of fuels, mainly by cars and trucks, accounts for almost 36% of avoided emissions; more efficient use of electricity in a wide range of applications for 30%; greater efficiency in energy production for 13%; renewables and biofuels for 12%; and nuclear for the remaining 10%.

2.1. Co-ordinating relevant policy fields

Energy contributes to and detracts from sustainable development according to an elaborate interplay of markets, technological development, government policies, social norms and individual behaviour, not just in the energy sector but in many other sectors as well. The relationship between energy and sustainable development is complex, both positive and negative [16–20].

On the positive side, it is the services that energy enables, not the energy itself, that most directly advance sustainable development. Better cooking, lighting, space conditioning, transportation, communications, income generating processes and other services are the means by which energy improves human, social, economic and environmental conditions. On the negative side, energy can be produced and deployed in ways that pollute the environment and increase greenhouse gas emissions. The development of various energy sources, including oil, gas and coal, can disrupt ecosystems if not carefully planned [21–23].

Energy is vital to providing an array of necessary services, but the nature of its contribution is not fixed. It is possible to alter the end-use devices, methods, infrastructure and behaviour that deliver these services to become more energy efficient or to use alternative types of energy. There are opportunities and barriers to developing and deploying more sustainable energy supplies and end-uses in various sectors, which are influenced by the [20]:

- availability, affordability, security, reliability and safety of energy supplies in the energy system;
- environmental friendliness of energy supplies in the energy system;
- planning, design, construction, operation, financing and pricing of energy-using buildings, industrial processes, transport systems, etc. in end-use sectors;
- social and cultural norms regarding behaviour in end-use sectors;
- access to alternative technologies and energy sources; and
- investment assistance to develop and deploy energy services.

Government policies are key to ensuring that the energy sector advances sustainable development. There are many policy domains where policies influence how and how much energy is produced, converted, transported, distributed and used. Ensuring that energy systems develop in a way that best supports and accords with sustainable development requires communication and co-ordination among all relevant policy areas at all levels of government [18–23].

Full communication and co-ordination across all policy domains affecting the development and use of energy are still rare, just as they are in many other fields. Addressing energy challenges requires an integrated sustainable development approach based on increased co-ordination among diverse fields and stakeholders. A wide range of government departments and agencies should be involved in the formulation and implementation of energy policies in various sectors [2,6].

3. Widening energy access in developing countries

3.1. Energy demand and poverty

Energy contributes to a virtuous cycle of human, economic and social improvements that are essential to sustainable development in developing countries (Fig. 2). Sufficient supplies of clean energy are the basis for raising standards of living, improving the quality and quantity of human capital, enhancing the business and natural environment, and increasing the efficiency of government policies [2,6,24–26].

However, energy poverty remains a major problem for human health, economic development and environmental sustainability in many parts of the world. Approximately 1.6 billion people mostly in the rural areas of Sub-Saharan Africa, South and East Asia, and Latin America lack access to electricity, and 2.5 billion people rely on traditional biomass for cooking and heating [2,6]. About 1.3 million people mostly women and children die prematurely every year because of exposure to indoor air pollution from cooking and heating with traditional, inefficient biomass stoves (see Fig. 3).

Demand for energy is growing exponentially in developing countries due to rapid population growth (especially in Africa) and rapid economic expansion (especially in China and India). This is projected to lead to a near doubling in primary energy use, much of it unsustainable, by developing countries in the next two decades.

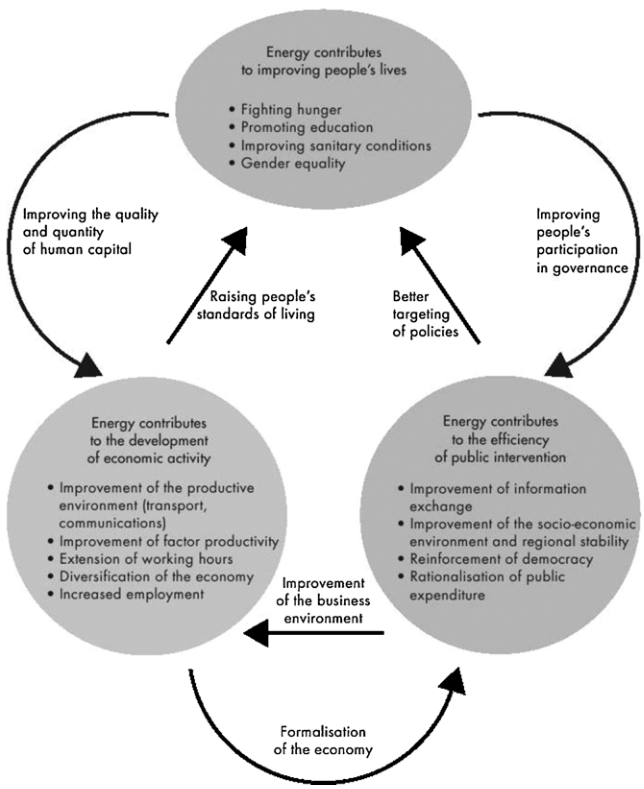

Fig. 2. Links between energy and human, economic and social development.

As a result of this growth, developing countries will account for 50% of primary energy use and 52% of energy-related CO_2 emissions by the year 2030 [27–31].

China will experience the greatest increase in energy demand, accounting for 43% of all developing country growth and 30% of total world growth. India, other Asia, the Middle East and Africa will show medium growth in energy consumption [14]. As for energy sources, coal will be the largest growing energy source followed by oil. Gas will continue to be used extensively in the Middle East and Latin America, while the consumption of biomass and waste will increase in Africa [6,14].

Huge investments are needed in additional and replacement capacity for producing, converting, transporting and distributing energy in developing countries to meet future needs (Fig. 4). Most of this investment is needed in the power sector, particularly in China, India and other Asian countries [1]. Other regions need financing also for oil and gas development and use [2]. On the other hand, investment at these high levels represents a dual challenge. Governments have to set policies that attract sufficient private investment and development assistance. Developing country governments, together with investors and donors, need to find more

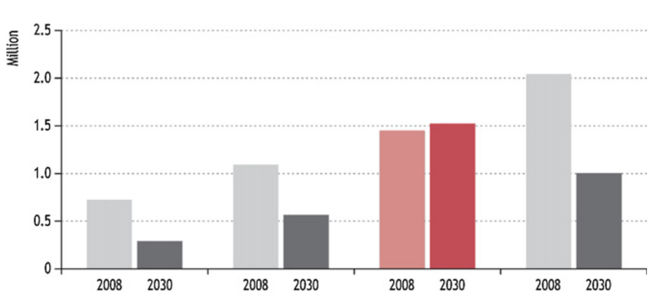

Fig. 3. Premature annual deaths from household air pollution and other diseases.

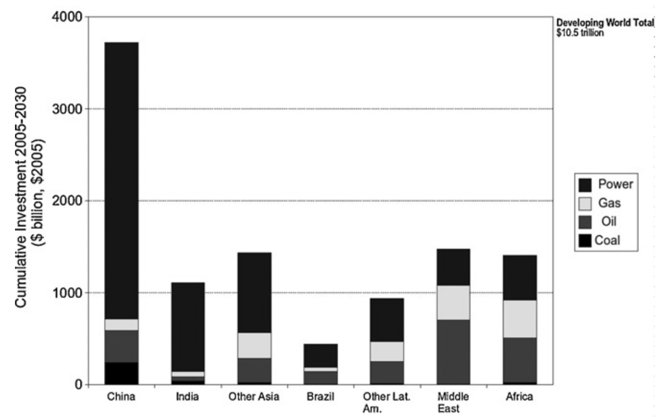

Fig. 4. Cumulative investment needed in energy infrastructure by region and fuel.

efficient and less expensive ways of delivering energy services so that the financial savings might be invested in other sustainable development needs. They should also ensure sustainable patterns of production and consumption of energy supplies and services [18–20].

3.2. Sustainable energy sources

Lack of access to affordable electricity and heavy reliance on the inefficient and unsustainable use of traditional biomass fuels (*i.e.*, fuelwood, charcoal, agricultural waste and animal dung) are both manifestations and causes of poverty. Electricity and other modern energy sources play a critical role in economic and social development. They alone cannot alleviate poverty but they are indispensable to sustainable development [2].

Modern energy services enhance the life of the poor in countless ways. Electric light extends the day, providing extra hours for reading and work. Modern cook-stoves save women and children from daily exposure to noxious cooking fumes. Refrigeration extends food freshness and avoids wastage. Clinics with electricity can sterilise instruments and safely store medicines through refrigeration. Manufacturing and service enterprises with modern energy can be more productive and can extend the quality and range of their products – thereby creating jobs and higher wages [1–10].

In many countries, poverty is prolonged particularly by the unsustainable collection of biomass and its use in traditional, inefficient stoves [32]. This creates indoor smoke pollution leading to serious health damage, such as respiratory diseases, obstetrical problems, blindness and heart disease. It requires large amounts of time for fuel gathering – reducing the time available for other productive activities, such as farming and education [28]. It causes ecological damage (*e.g.* deforestation and soil erosion) and local scarcity of wood in some areas. And it draws agricultural residues and dung away from their use as fertilizer, thus reducing agricultural productivity [27–30].

It is estimated that to achieve the Millennium Development Goals (MDGs), the number of people lacking electricity would need to decrease to below 1 billion and those relying on traditional biomass would need to fall to 1.2 billion by 2015 [18]. Concerted government action with support from the industrialised countries is needed to achieve these targets, together with increased funding from both public and private sources [2]. On the other hand, policies need to address barriers to access, affordability and supply of electricity and alternative fuels, which are already available at reasonable cost, *e.g.* gas-fired stoves and cylinders. Access to sustainable energy sources should form a central component of broader development strategies [24–27].

3.3. Industrial development for energy needs

Advancing development on a sustainable path and securing the investments needed to meet rapidly growing energy demand require active participation by the private sector [6]. Governments must set out attractive frameworks for domestic and foreign investment plus enforceable rules on corporate and business behaviour. The good governance practices which attract business investment are generally the same as those which encourage good environmental and social behaviour on the part of both industry and governments [2].

Public policies promoting responsible business conduct include providing an enabling environment which clearly defines the respective roles of government and business; promoting dialogue on norms for business conduct; and supporting private initiatives and international cooperation initiatives in support of responsible business conduct [18]. There are a wide range of voluntary codes of conduct for sustainable development developed by international governmental bodies and business associations. These provide guidelines for the ethical behaviour of companies to encourage the incorporation of socio-environmental concerns in their business practices [18–20].

4. Energy research and development

The challenges of long-term energy security and environmental sustainability can only be met through the deployment of efficient and less expensive technologies that are capable of using more plentiful, cleaner and cheaper sources of energy. In addition to the diffusion of current clean energy technologies, better technologies need to be developed and implemented [18]. However, the continuation of current energy research and development (R&D) spending trends is inadequate to deliver the technological advances needed [20]. To promote sustainable energy innovations, research policy and energy policy should be harmonised and coordinated to a far greater degree than is currently the case.

Given limited resources, setting research priorities for sustainable energy technologies must take into account their contributions to reducing greenhouse gas emissions as well as relative incentives for private *vs.* public investments. For example, the declining share of public funding for mature fossil fuel R&D is justified given the maturity of the technology and the strong incentives for the private sector to invest in them. These technologies are often commercially exploitable because they increase efficiency or make extraction and production processes more effective [17–20].

Technologies with major R&D needs which can contribute large CO_2 reductions include carbon capture and storage (CCS) for power generation and industrial applications. CCS research is increasing but is still very low [33]. There is a shortage of sizeable R&D projects to advance technological understanding, increase efficiency and drive down costs. On the other hand, renewables should be an R&D priority [10]. Given the enormous scale of the resource, research receives only modest funding, although its share has been rising slightly in recent years. The level of solar electric research in particular seems to be relatively modest given its potential, notably in developing countries [6]. Research and development investment devoted to more mature renewable technologies such as geothermal, biomass, wind and hydropower to provide heat, electricity and transport fuels can also result in cost reductions and efficiency performance improvements as more experience is gained. Their deployment depends partly on the relative pricing of alternative fuels such as oil, coal and gas, but technical advances are possible to improve their competitiveness [33–38].

4.1. Developing climate-friendly products and processes

The vast development and deployment of cleaner, more energy efficient technologies will be needed to reduce greenhouse gas emissions. Investment is needed in a broad portfolio of technologies. In an analysis of technology pathways for reducing CO_2 emissions to current levels by 2050, energy efficiency in end uses was found to be indispensable, accounting for 45% of emission reductions (Fig. 5). Other technological contributions could be made by carbon dioxide capture and storage (CCS) in power generation and industry (20%), the use of renewables in power generation (10%), and biofuels in transport (6%) [2,6,13,14].

A variety of barriers discourage the deployment of these climate-friendly approaches. Some have technical problems rendering them unsuitable for the market and in need of further R&D. When a technology is technically proven, demonstration projects are required to show that it works on a commercial scale and under relevant operating conditions. Others face cost barriers in that they are priced higher than incumbent technologies [21]. Efficient end-use technologies can face still other barriers in the form of lack of awareness of their benefits relative to costs, lack of market acceptance, and lack of incentives for sustainable consumption by individuals and industry [2,6,23].

For the short and medium term, policies that target fuel efficiency offer the most potential for reducing CO_2 emissions in transport. Higher cost energy sources, including clean energy carriers such as hydrogen and electricity, produced from renewable energy sources, or from fossil fuels with carbon sequestration and storage, will be required if there are to be meaningful cuts in transport sector CO_2 emissions [36]. A switch to hydrogen fuel-cell

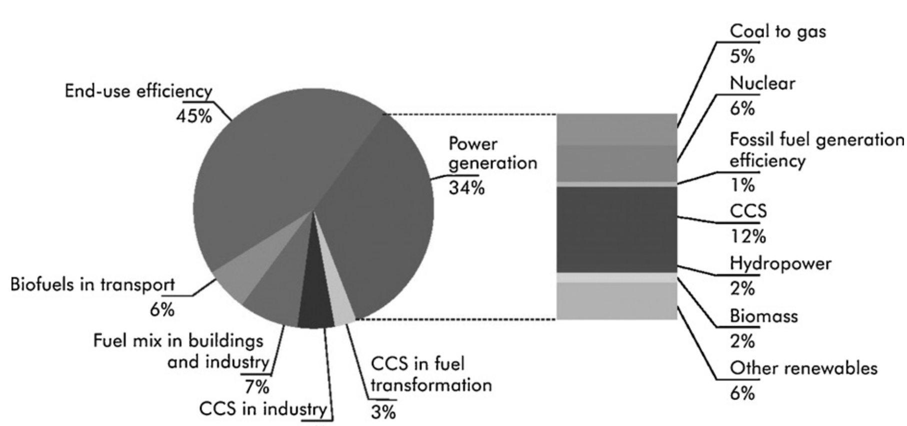

Fig. 5. Potential reductions in CO_2 emissions by technology area.

technologies will require huge infrastructure investments, while major R&D programmes will be needed to bring these technologies to commercial viability [34–37].

The transfer and diffusion of clean energy technologies will also require a broad portfolio of policy tools. Technology "push" alone is unlikely to deliver the large long-term emission reductions that are needed. Policies for both technology development and "market pull" are required, including price signals through taxes and economic instruments. International collaboration can pool intellectual resources and investment to enhance clean energy deployment. However, domestic policy frameworks are also important for technology deployment and diffusion [2].

5. Promoting energy efficiency

5.1. Increasing energy efficiency

Improving energy efficiency is the cheapest, fastest and most environmental friendly way to meet a significant portion of the world's energy needs. Improved energy efficiency reduces the need for investing in energy supply. Many energy efficiency measures are already cost-effective, and they will pay for themselves over their lifetime through reduced energy costs. Energy conservation is any behaviour that results in the use of less energy [1,4].

Energy efficiency options are generally characterised as having technical and cost barriers that are secondary to other barriers, such as lack of public acceptance, financing, information, education or proper incentives. The exceptions are some industrial options, hybrid vehicles, and certain forms of power generation. But in general, the deployment of energy efficiency options is not delayed due to need for further technical development or cost reductions [22,23].

Countries need to pursue energy efficiency policies more diligently in the long-term regardless of the development of fuel prices. In most countries, energy efficiency policy does not receive sufficient emphasis. It tends to receive less attention than renewable energy policy even though they both have similar benefits in terms of energy security and climate change mitigation. At the same time, energy efficiency approaches are often more cost-effective [2].

There are diverse barriers to greater deployment of energy efficient options. Consumers are often ill-informed and few are concerned with energy efficiency when buying appliances, homes or cars. Business management tends to give energy efficiency a low priority in decision making. There are opportunities for energy efficiency that consumers never see because the manufacturers of refrigerators, televisions or cars do not always take full advantage of the technologies that exist to make their products more energy efficient [23].

To advance energy efficiency, governments should employ the range of available policy instruments, including regulations and standards, fiscal incentives, public information campaigns, labels, and public-sector leadership in procurement. These can be deployed in a range of sectors [2,6,22,23]:

- New buildings could be made 70% more efficient than existing buildings through use of insulated windows, modern gas and oil furnaces, and more efficient air conditioners. District heating, heat pumps and solar energy can all save energy. Improved lighting could yield cost-effective savings of 30–60%.
- For households, major improvements have been made in refrigerators, water heaters, washing machines and dishwashers. New technologies such as "smart" metering, micro combined-heat-and-power generation, fuel cells, solar photovoltaic and more efficient lighting can save energy.
- In industry, energy demand and CO_2 emissions can be cut through improved efficiency of motors, pumps, boilers and heating systems; energy recovery in material-production processes; recycling of used materials; and higher efficiency of materials use.
- In transport, the efficiency of conventional gasoline and diesel vehicles can be improved through turbochargers, fuel injection and advanced electronic methods of engine control; new materials and more compact engines; efficiency gains in vehicle air conditioning; and hybrid vehicles and advanced diesel engines.

5.2. Making fossil fuels more climate-friendly

The use of fossil fuels such as coal, oil and natural gas can be made more climate friendly through two primary means [39]:

- carbon dioxide capture and storage (CCS) at power plants and industrial facilities, and
- substitution to lower-carbon fuels in power plants and industry.

Carbon capture and storage (CCS) involves capturing the CO_2 generated at power plants and industrial facilities and storing it underground, *e.g.* in depleted oil or gas fields. These underground reservoirs could allow storage for decades and the captured CO_2 may also be used to enhance the output of oil and gas in the respective fields [33–36].

The main capture potential is in the electricity sector, but interesting opportunities exist in synthetic transport fuel processing and industrial sectors, where CCS could reduce CO_2 emissions from coal and natural gas use to near zero. Because, most CO_2 emissions are released from coal-fired power plants, more than half of the potential of CCS is associated with coal fired processes. Clean coal technologies with CCS offer an important opportunity to constrain emissions and provide lower-cost electricity in rapidly growing economies with large coal reserves, such as China and India [14].

Research and development on CCS need to be greatly expanded, public awareness and acceptance of storage options should be heightened, and policy incentives including a value for carbon are needed to stimulate the uptake of CCS technologies. Emission trading systems may offer such incentives, if carbon prices are high enough to make CCS competitive. There is also need for integrated full-scale demonstration plants for CCS technology. Efficient coal combustion technologies such as high-temperature pulverised coal plants and integrated coal-gasification combined-cycle (IGCC) should be used in conjunction with CCS [33–35].

For fuel switching, natural gas can be used as a substitute for coal and heavy oil products in power production and a variety of industrial processes. In power generation, fuel switching from coal to gas can reduce CO_2 emissions by 50–75%. Natural gas combined cycle (NGCC) power plants are more efficient than coal-fired power plants, but the expansion of this technology is limited by uncertainty about future natural gas prices. Fuel costs account for 60–85% of total generation costs for NGCCs, much higher than for other power generation technologies. Fuel switching will be limited in the absence of CO_2 policies that place a value on carbon [13].

In industry, there are opportunities to substitute natural gas for coal in the manufacture of basic materials. For example, gas-based direct reduced iron (DRI) processes can be used in place of coal-based blast furnaces in steel production. In principle, the potential is very high, but so is the cost. The costs of a switch from coal to gas can be low if inexpensive stranded gas can be used. This implies relocation by industry to places where cheap gas resources exist. The main barriers are cost and an increased dependency on natural gas imports.

Table 4
Global modern renewable energy supply and shares.

	2000	(%)	2008	(%)	2020	(%)
Electricity (TWh)	2876	19	3774	19	8646	25
Heat (Mtoe)	266	10	312	10	442	12
Biofuels (Mtoe)	10	1	45	2	86	3

Table 5
Shares of renewable energy by sector and region.

	Electricity generation		Heating purpose		Biofuels for Transport	
	2008	2020	2008	2020	2008	2020
OECD	17%	25%	11%	18%	3%	10%
Europe	21%	35%	12%	20%	3%	10%
USA	9%	20%	10%	16%	4%	10%
Japan	10%	15%	3%	5%	0%	1%
Non-OECD	21%	25%	9%	10%	2%	5%
China	17%	20%	1%	3%	1%	3%
India	16%	20%	24%	20%	0%	4%
Brazil	84%	70%	47%	50%	21%	35%
Russia	16%	24%	5%	5%	0%	1%
Africa	16%	25%	31%	32%	0%	1%
World	19%	25%	10%	12%	3%	5%

5.3. Expanding the role of renewables

Hydropower, biomass combustion, solar water heating and geothermal technologies are mature and commercially viable in many situations. The principal impediment to the wider commercialisation of other renewable energy technologies (see Tables 4–6) is their higher cost compared to conventional technologies and, in the case of wind, wave and solar, their short-term variable character [6,21–23].

To overcome cost barriers, carbon emissions and related externality costs need to be accounted for to raise the price of conventional fossil fuels relative to renewables. In addition, further research is needed on manufacturing and interconnection processes. In this way, renewable energy technologies could fulfil their large potential contributions to energy security, climate change mitigation and economic development [40–44].

Hydropower is already widely deployed and is, in many areas, the cheapest source of power. However, there is considerable potential for expansion, particularly for small hydro plants. Current requirements include continuous improvements in technology, increased public acceptance, and streamlining the project approval process [6,10].

The costs of onshore and offshore wind power have declined sharply in recent years through mass deployment, the use of larger components, and more sophisticated controls on wind turbines. The best onshore sites are already cost competitive with other power sources, while offshore installations are more costly, especially in deep water. In situations where wind will have a very high share of total generation, it will need to be complemented by sophisticated networks, improved forecasting, back-up systems or storage, to accommodate its variability. Minimising environmental impacts is also important as well as education of the public regarding deployment [45].

Table 6
Share of electricity from renewables in some developing countries.

Country/region	Existing share (2008)	Future target (2020)
World	18.0%	20%
EU-27	16.7%	25%
Algeria	10%	20%
Argentina	35%	45%
Brazil	85%	85%
China	17%	25%
Egypt	10%	20%
India	6%	25%
Morocco	4%	25%
Nigeria	2%	5%
Nicaragua	27%	50%
Pakistan	5%	14%
South Africa	1%	4%

Table 7
Number of people relying on the traditional biomass use as their primary cooking fuel (million).

	2009			2020
	Rural	Urban	Total	Total
Africa	481	176	657	776
Sub-Saharan Africa	477	176	653	772
Developing Asia	1694	243	1937	1840
China	377	47	423	326
India	765	90	855	823
Other Asia	553	106	659	687
Latin America	60	24	85	81
Developing countries[a]	2235	444	2679	2772
World[b]	2235	444	2679	2772

[a] Includes Middle east countries.
[b] Includes OECD and transition economies.

The costs of high-temperature geothermal resources for power generation have dropped substantially since the 1970s. Geothermal is a site-specific resource that can only be accessed in certain parts of the world for power generation [9]. Lower-temperature geothermal resources for direct uses like district heating and ground-source heat pumps are more widespread. R&D including for deeper drilling, hot dry rocks, and binary systems can further reduce the costs and increase the scope of geothermal power [22,23].

Solar photovoltaic technology is playing a rapidly growing role in niche applications. Costs have dropped with increased deployment and continuing R&D [1,4,9]. Concentrating solar power (CSP) also has promising prospects and several new commercial plants are under construction or planning. However substantial cost reductions are still needed [46].

The combustion of biomass for power generation is a well-proven technology. It is commercially attractive where quality fuel is available and affordable [1]. Co-firing a coal-fired power plant with a small proportion of biomass requires no major plant modifications, can be highly economic and can also contribute to CO_2 emission reductions [9]. The use of biomass, geothermal and solar thermal systems for heating and cooling has considerable potential for increasing the share of renewable energy in many countries. Relatively few policies presently exist to encourage greater deployment but where they do, substantial market growth has occurred [47]. Table 7 shows the number of people relying on the traditional biomass use as their primary cooking fuel [6].

Liquid biofuels currently meet around 1–2% of the global road transport energy demand [6]. Considerable interest has occurred recently in many countries to expand this share and targets and policies have been developed [5–7]. There is potential for second generation biofuels from ligno-cellulosic feedstocks and trade between north and south [6]. However concerns are growing as to the sustainability of the biomass feedstock resource, and impacts on food, land use and water supplies.

6. Benefiting from energy-related climate change policies

6.1. Promoting use of economic instruments

Economic or "market-based" instruments can be an effective and economically efficient means of achieving sustainable energy

policy goals in many circumstances. These include taxes, emission trading, subsidy reform, and preferential tariffs. On the other hand, economic instruments offer the potential for both static efficiency and dynamic efficiency. They provide increased flexibility for governments and industry through building on the operation of the market and the price system. They can provide government revenue that can be used for a variety of purposes [2,20].

Environmentally related taxes introduce price signals so that producers and consumers take into account the costs of pollution and resource use associated with their activities. In this way, carbon taxes would internalise the cost of greenhouse gas emissions and raise the price of certain fuels, processes and products. These fiscal incentives would reduce demand for harmful products and increase demand for alternative fuels such as renewables whose prices become more competitive. Environmentally related taxes also increase incentives for the private sector to undertake R&D on sustainable innovations and technologies.

Concern about reducing the competitiveness of energy-intensive sectors is a major obstacle to the full implementation of carbon taxes. Energy intensive industries often receive total or partial exemptions from such taxes even though significant global reductions in carbon emissions could be achieved. In levying carbon taxes, the competitiveness impacts can be reduced by:

- enlarging the group of countries that put similar policies in place,
- levying border tax adjustments on products from countries having less stringent taxes,
- recycling a portion of the tax revenues back to the affected firms.

Many countries are now considering such approaches for using carbon taxes to promote more sustainable energy systems. On the other hand, emission allowance trading is the premier instrument for reducing greenhouse gas emissions from energy production and use [13]. This involves applying surplus emission reductions at certain facilities to meet or redefine emission reductions at other sources. The schemes have different sizes, geographical scopes, time-periods, design characteristics, compliance provisions, and rules for “offset” credits. Some are designed to be used for compliance with emission commitments under the Kyoto Protocol, while others are planned or in use in non-Kyoto parties.

The different schemes could be linked into an international trading system in the future. Trading schemes can trigger many of the local actions needed to curb emissions and would be most efficient with widespread coverage. Domestic trading schemes could expand beyond their current coverage of large stationary emission sources. A global market could incorporate domestic and regional schemes with divergences in design. However, the energy realities of developing countries give most of them little incentive to develop their own broad domestic emission trading schemes [2].

Subsidies can be used to lower energy prices, which can raise living standards and increase economic activity, but which can also discourage the adoption of energy efficient devices. Energy subsidies raise the profitability of energy producers, which may encourage or discourage shifts in the fuel mix. Transport subsidies can increase transport activity and favour certain modes of transportation, which increase negative environmental impacts. Industrial subsidies may prompt delays to plant restructuring and lead to prolonged inefficiencies in the use of energy [11,26].

Energy-related subsidies can have broad impacts on sustainability [2]. They can encourage overuse of fossil fuels and lead to the over-exploitation of resources while contributing to harmful emissions and waste. Socially, these supports can redistribute income from consumers to producers and distort resource allocations across firms and sectors as well as countries. Subsidies may, however, be justified in some cases in order to combat poverty, but should be crafted carefully for these purposes [18–20].

Tariff reductions for renewable energy and associated technologies would reduce the tax that consumers in some countries pay on these goods. Preferential tariff margins for energy-efficient goods could be part of general trade negotiations. This would benefit those living in rural areas of developing countries where many renewable energy technologies would make a great contribution to energy supply, but are currently too expensive partly due to import taxes. It would help reduce dependence on more polluting and less secure energy sources. To the extent that reducing import tariffs also reduces the costs of grid-connected technologies, these would also become a more affordable option in the portfolio of energy options available to electric utilities. Manufacturers located in developing countries alike would benefit from increased trade in renewable energy technologies and components.

6.2. Clean Development Mechanism (CDM)

Under the Clean Development Mechanism (CDM), industrialised countries can achieve some portion of their required greenhouse gas commitments under the Kyoto Protocol from “credits” generated through lower-cost emission reductions in projects beyond their own borders. Governments, investors and private companies in industrialised countries cam receive credits for reduction projects they carry out in “host/seller” countries. Each CDM project must [6,23,35]:

- reduce GHG emissions above and beyond “business as usual”;
- account for GHG emissions that occur outside the project boundary that are attributable to the project;
- adhere to strict physical boundaries within which GHG emissions will be reduced;
- not involve nuclear technology nor exceed internationally agreed limits on forestry credits and activities;
- be voluntary and have the host country’s approval;
- meet the sustainable development goals defined by the host country;
- include the participation of affected communities, groups or individuals;
- not contribute to environmental decline;
- occur in a developing country that is Party to the Kyoto Protocol.

There has been a rapid growth in activity under the CDM, which is currently expected to lead to emission mitigation of more than 1.8 billion tons from over 1700 individual projects by 2012 [23]. However, although there is an enormous potential for renewable energy and energy efficiency projects, much of it remains “untapped”, with these project types only accounting for about a fifth of total expected credits from the CDM. There are several reasons for this at the national, international and project levels, including limited institutional capacity, difficulties in obtaining sufficient project finance in countries with a high sovereign risk, and the relatively small size of many renewable energy and energy efficiency projects [6].

The sectoral crediting mechanism (SCM) would focus on economic sectors, rather than projects, in developing countries. Emission performance baselines for a specified period would be established for selected sectors (*e.g.* iron and steel and cement) in participating developing countries. These countries would then receive tradable emission reduction credits, which they could use as they wish – distributing them to individual companies in the sector or selling them for general revenue [21–23].

Sectoral crediting mechanisms are a promising means to encourage investment in climate-friendly energy systems. Nevertheless, developing an effective system that is feasible to negotiate and set up presents certain challenges due to wide variations in greenhouse gas intensities among countries and facilities, and the

need for technical skills for evaluating, monitoring and verifying sectoral crediting proposals. The demand for credits must be relatively certain to make the effort worthwhile, and the environmental effectiveness of the instrument must be secured.

7. Results and discussion

The World Energy Outlook assesses two indicators of energy poverty at the household level: the lack of access to electricity and the reliance on the traditional use of biomass for cooking. In Sub-Saharan Africa the electrification rate is 31% and the number of people relying on the traditional use of biomass is 80%: this is where the greatest challenge lies [6].

Today, there are 1.4 billion people around the world that lack access to electricity, some 85% of them in rural areas. Without additional dedicated policies, by 2030 the number of people drops, but only to 1.2 billion. Some 15% of the world's population still lack access, the majority of them living in Sub-Saharan Africa. On the other hand, the number of people relying on the traditional use of biomass is projected to rise from 2.7 billion today to 2.8 billion in 2030. Using World Health Organization estimates, linked to our projections of biomass use, it is estimated that household air pollution from the use of biomass in inefficient stoves would lead to over 1.5 million premature deaths per year, over 4000 per day, in 2030, greater than estimates for premature deaths from malaria, tuberculosis or HIV/AIDS [3].

Addressing these inequities depends upon international recognition that the projected situation is intolerable, a commitment to effect the necessary change, and setting targets and indicators to monitor progress. A new financial, institutional and technological framework is required, as is capacity building in order to dramatically scale up access to modern energy services at the local and regional levels. On the other hand, it provides a monitoring tool, the Energy Development Index (EDI), that ranks developing countries in their progress towards modern energy access [2–6].

The UN Millennium Development Goal of eradicating extreme poverty by 2015 will not be achieved unless substantial progress is made on improving energy access. To meet the goal by 2015, an additional 395 million people need to be provided with electricity and an additional 1 billion provided with access to clean cooking facilities. This will require annual investment in 2010–2015 of $41 billion [3].

To meet the more ambitious target of achieving universal access to modern energy services by 2030, additional investment of $756 billion, or $36 billion per year, is required. This is less than 3% of the global energy investment projected in the New Policies Scenario to 2030. The resulting increase in primary energy demand and CO_2 emissions would be modest. In 2030, global electricity generation would be 2.9% higher, oil demand would have risen less than 1% and CO_2 emissions would be 0.8% higher [3,6].

The poorest households tend to use three-stone fires for cooking. The high moisture content of the biomass resources used and the low efficiency of the combustion process produce dangerous levels of smoke, particularly if food is cooked indoors. The efficiency of biomass can be increased through provision of improved stoves and enhanced ventilation. Adding chimneys to stoves with low combustion efficiency can itself be a useful improvement, as long as the chimney is kept clean and maintained [1–4].

However, often there is some leakage into the room and the smoke is merely vented outside the house and will, in part, re-enter the dwelling, so this option is not as effective as a change to clean fuels or advanced biomass stoves. Experience suggests that in order for biomass gasifiers for cooking to consistently achieve emissions close to those of liquefied petroleum gas (LPG) stoves, the stove requires assisted air flow by use of a fan. Ventilation of the home can contribute to reducing household air pollution but alone is unlikely to make a substantial difference if there is a highly polluting indoor source [3].

Lighting in low-income households in developing countries is generally provided by candles or kerosene/diesel lanterns [1–4]. Candles and low-efficiency lanterns emit smoke. Kerosene lamps produce better light, but they are uncomfortably hot in a tropical climate and they can be difficult to light. Use of kerosene also imposes health risks, through fires and children drinking fuel stored in soft drink bottles, and there is emerging evidence of links with tuberculosis and cancer [3]. Switching to electricity eliminates these risks and increases efficiency. There has been much recent success in the dissemination of compact fluorescent light bulbs (CFLs) in many developing countries. High-quality CFLs are four to five times more efficient than incandescent bulbs and last much longer. Large-scale deployment of CFLs can help reduce peak electricity needs and ameliorate infrastructure shortages [4–6].

Grid extension in rural areas is often not cost effective. Small, stand-alone renewable energy technologies can often meet the electricity needs of rural communities more cheaply and have the potential to displace costly diesel-based power generation options. Specific technologies have their advantages and limitations. Solar photovoltaic (PV) is attractive as a source of electric power to provide basic services, such as lighting and clean drinking water. For greater load demand, mini-hydro or biomass technologies may offer a better solution, though PV should not be ruled out of consideration as system prices are decreasing [4–6]. Moreover, PV can also be easily injected in variable quantity into existing power systems. Wind energy represents a good cost-competitive resource, with mini-wind prices below those of PV [1–3]. Wind energy systems are capable of providing a significant amount of power, including for motive power. One of the main advantages of renewable energy sources, particularly for household-scale applications, is their comparatively low running costs, but their high upfront cost demands new and innovative financial tools to encourage uptake. To combine these different sources of energy in a power system supplying a mini-grid is probably the most promising approach to rural electrification. It is important that subsidised delivery mechanisms make provision for maintenance and repair.

Improved irrigation is vital to reducing hunger and saving dwindling water resources in many developing countries. Drip irrigation is an extremely efficient mechanism for delivering water directly to the roots of plants. It increases yields and allows for introduction of new crops in regions and in seasons in which they could not be sustained by rainfall alone. Solar-powered pumps save hours of labour daily in rural off-grid areas, where water hauling is traditionally done by hand by women and children. These pumps are durable and immune to fuel shortages. In the medium term, they cost less than diesel-powered generators [6].

Village level energy services, both for electricity and mechanical power, are extremely important. In poor rural areas, providing household level electricity service is often not economically feasible. The cost of service provision is higher than in urban areas, because support infrastructures for maintenance are lacking and because low population density increases the cost per household. Where household level electrification is not feasible, providing electricity at the village level for productive activities and basic social services can be a useful stepping stone. Moreover, village level energy installations, *e.g.* mechanical power for food processing and other productive activities, irrigation, and clean water and sanitation, have a significant impact on poverty, health, education and gender equality [1].

While mechanical power is critical to develop industrial and productive activities necessary to local development, quantified objectives defining rates of access to mechanical power are rarely integrated into national strategies. By the end of 2009, less than 5% of developing countries had defined such targets. Those few

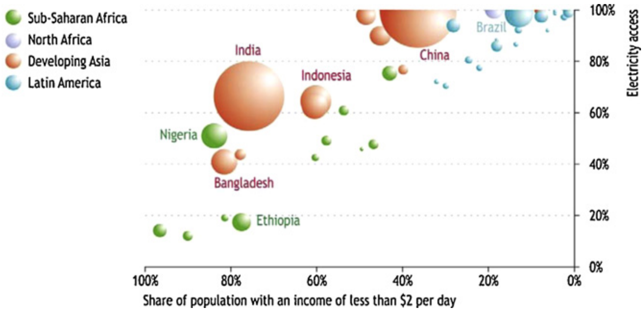

Fig. 6. Household income and electricity access in developing countries.

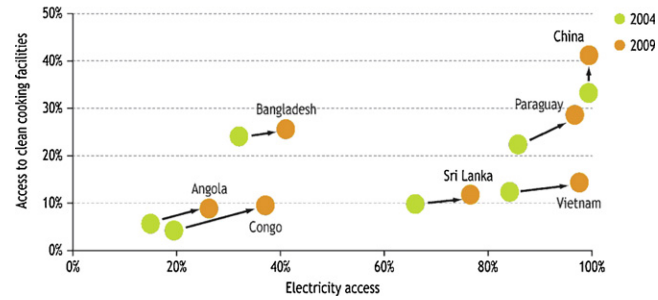

Fig. 8. Evolution of household access to modern energy in selected developing countries.

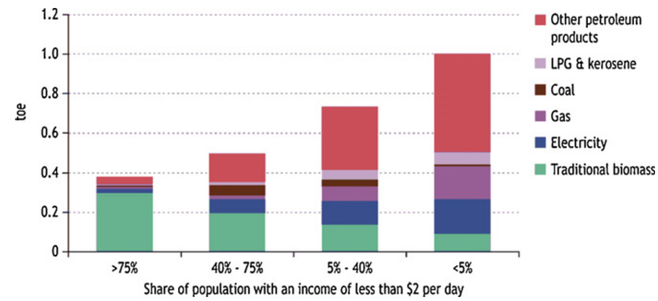

Fig. 9. The relationship between per-capita final energy consumption and income in developing countries.

countries that had established targets on access to mechanical power are all in Sub-Saharan Africa [3].

Access to modern forms of energy is essential for the provision of clean water, sanitation and healthcare and provides great benefits to development through the provision of reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunication services. The close correlation between income levels and access to modern energy: surprisingly, countries with a large proportion of the population living on an income of less than $2 per day tend to have low electrification rates and a high proportion of the population relying on traditional biomass (see Fig. 6). Access to electricity rises faster than the access to modern cooking fuels, largely because governments give higher priority to electrification, though access to both electricity and clean cooking facilities is essential to success in eradicating the worst effects of poverty and putting poor communities on the path to development [3].

There are currently about 2.7 billion people in developing countries who rely for cooking primarily on biomass, including wood, charcoal, tree leaves, crop residues and animal dung, used in inefficient devices. This number is higher than previously estimated value due to population growth, rising liquid fuel costs and the global economic recession. About 82% of those relying on traditional biomass live in rural areas, although in Sub-Saharan Africa, nearly 60% of people living in urban areas also use biomass for cooking. The share of the population relying on the traditional use of biomass is highest in Sub-Saharan Africa and India as shown in Fig. 7 [3].

Many countries have made notable progress in improving access to electricity and clean cooking facilities since 2004, when the Energy Development Index was first created [4]. In all countries both the absolute number with access and the share of the population with access have increased (Fig. 8). In China, substantial progress has been made in the delivery of access to modern cooking fuels. In Angola and Congo, where the share of the population with electricity access and access to modern cooking fuels has expanded, most of the achievement has come from urban areas [3–6].

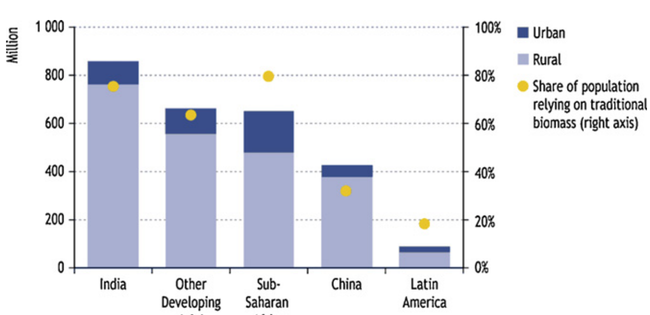

Fig. 7. Number and share of population relying on the traditional use of biomass as their primary cooking fuel in 2009. *Includes developing Asian countries except India and China.

Fig. 9 shows the relationship between fuel use and income across a range of developing countries. In low-income countries, final consumption of energy in the residential, services, industry and transport sectors is low and comprises mainly biomass. In high-income developing countries, the fuel mix is much more diverse and the overall amount of energy consumed is much higher. Demand for mobility, which is indicated where the share of other petroleum products in final energy consumption is high, is much greater in countries with a very low percentage of the population living on less than $2 per day.

8. Conclusions

Energy is essential for development; energy that is secure, environmental friendly, and produced and used efficiently is essential for sustainable development. Today's energy system is a cornerstone of modern life. It enables innumerable services capable of improving human, social, economic and environmental conditions in developing countries. Yet the current system of energy supply and use is highly unsustainable, and absent major new government policies will become even less so in the foreseeable future. It is insecure and unreliable, because of the heavy dependence on conventional oil, coming from limited reserves concentrated in politically volatile regions, and the inadequate capacity and maintenance of the network infrastructures for delivering gas and electricity. It is environmentally harmful, because of its predominant contribution to anthropogenic global warming, and its heavy contribution to local pollution.

The challenges of ensuring energy for sustainable development are many. Improving the human, economic, social and environmental conditions of the people of today and tomorrow demands much greater levels of energy services. It also demands that these services be delivered in a manner that is more universally accessible, affordable, reliable, safe and environmental friendly. This will require fundamental changes in technologies, methods, infrastructure and people's behaviour everywhere. The change needs to be so profound that government, business and social leaders need to

use every instrument at their disposable as effectively and efficiently as possible. Energy development and use should be placed in a sustainable development context to ensure that no dimensions, resources or policy tools are overlooked.

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